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13. ABSTRACT *(Maximum 200 words)*

This equipment has played a vital role in our development of wide-gap GaN and related AlInGaN alloy semiconductors that are rapidly finding application in optoelectronic and high temperature devices. In particular, the high resolution X-ray diffractometer has enabled us to understand how the thin, low-temperature buffer layer, that is grown before the main III-N epilayer, controls the crystallinity of the epitaxial film. The 244nm laser is being used as a pump laser for III-N materials and in combination with the XRD system is providing a rapid measure of alloy composition and crystal quality. These measurements are beginning to reveal important information concerning the stability of indium containing III-N alloys, that will have a major impact on heterostructure design.

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Characterization Equipment to Enhance Development of Group III-Nitride Wide Gap Semiconductors

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FINAL REPORT

APRIL 1996

prepared by

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1. Introduction

We are pleased to report that the equipment purchased under this DURIP contract is now installed and actively serving its intended purpose of providing advanced characterization of MOCVD grown GaN and related AlInGaN alloy, wide-bandgap semiconductors.

2. Philips High Resolution X-Ray Diffraction System

2.1 Buffer Layer Studies

This state of the art HRXRD instrument is being used to determine the microstructural properties of GaN and related semiconductor alloys. We have observed that the GaN nucleation or buffer material, that is deposited at low temperature (~500C), critically controls the crystalline, electrical and optical properties of the main III-N epilayers that are grown at higher temperature. The buffer material is often amorphous in its as deposited state but as the growth temperature is raised to 1050C the layer becomes polycrystalline. The high count rate and excellent resolution of the Philips XRD system has allowed us to track the evolution of this crystallinity even in buffer layers as thin as 200Å and figure 1 (lower figures) illustrates this transition to a polycrystalline state. AFM measurements on the same samples (upper images in figure 1) reveal that this buffer redistribution forms discrete growth islands that then act as nucleii for separate polycrystal grains during the higher temperature growth stage.

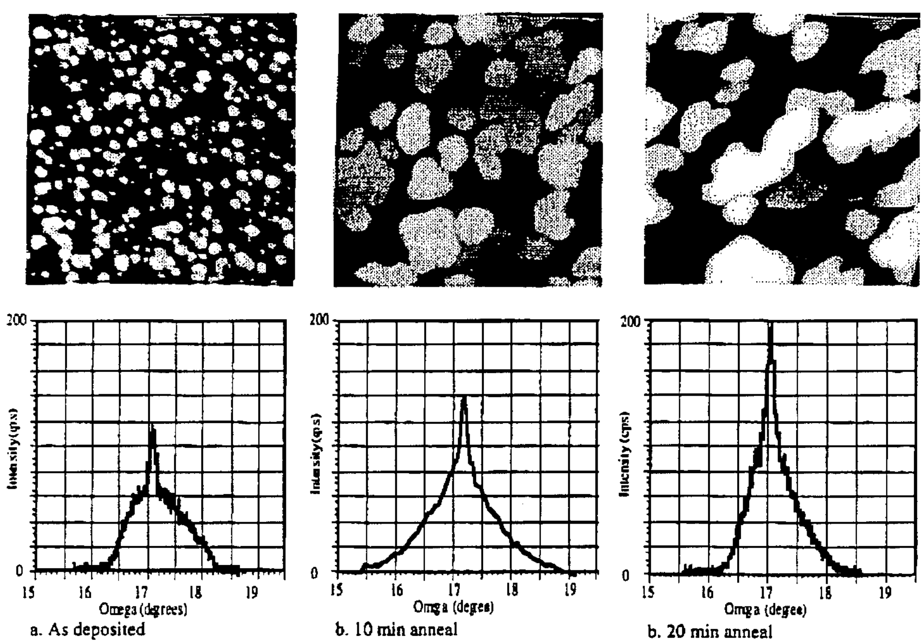

Figure1: AFM and XRD data for GaN buffer layers on c-plane sapphire for different ramp anneal times. The AFM image area is 0.4 mm x 0.4 mm, with lighter regions corresponding to higher surface features.

The eventual crystalline state of the buffer and of the main epilayers grown on top the buffer, are critically controlled by the deposition conditions of the buffer and by the conditons used during the ramp to higher growth temperature.

2.2 InGaN XRD Studies

The advanced automation capabilities of the Philips instrument has allowed us to perform lengthy (~ 20 hours) Omega vs. Omega/2Theta 2D maps, on thin layers of GaN and InGaN, AlGaN alloys. These maps (see figure 4) reveal that inspite of the large lattice mismatch between GaN and the sapphire substrate, the residual strain in the III-N epilayers is small and comparable with that found in homoepitaxial growth (~ 30 arcseconds). However, these plots also reveal a large mosaicity (range of "c" axis directions) that confirms the polycrystalline nature of the III-N epilayers. The mosaicity remains approximately constant for different alloy compositions within a heterostructure, which confirms that the orientation of individual polycrystals is "set" at the buffer/substrate interface and is invariant after that.

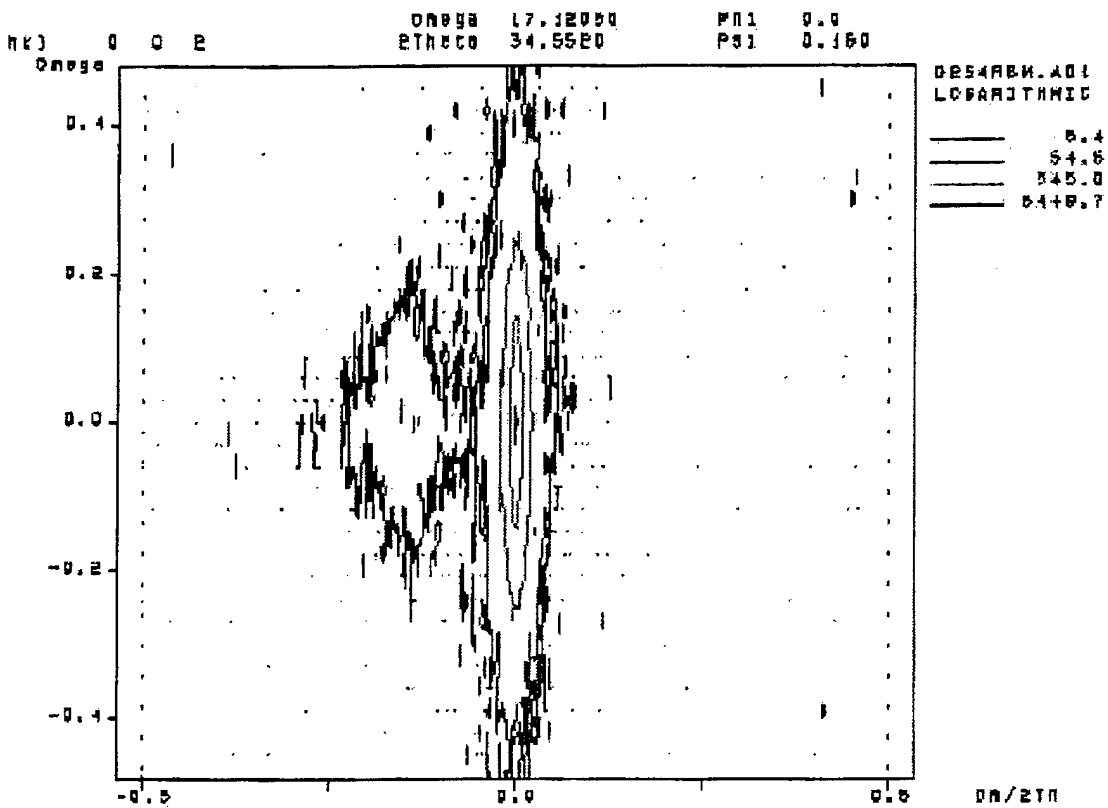

Figure 3. A reciprocal space map of an InGaN/GaN heterostructure. The vertical axis represents the Omega (rocking curve) measurement while the horizontal axis represents the Omega/2-Theta measurement. The vertical width of the peaks therefore reflects sample mosaicity while the horizontal axis reflects lattice strain.

3. UV Photoluminescence System Built Around Coherent Inova FrED 244 nm Pump Laser

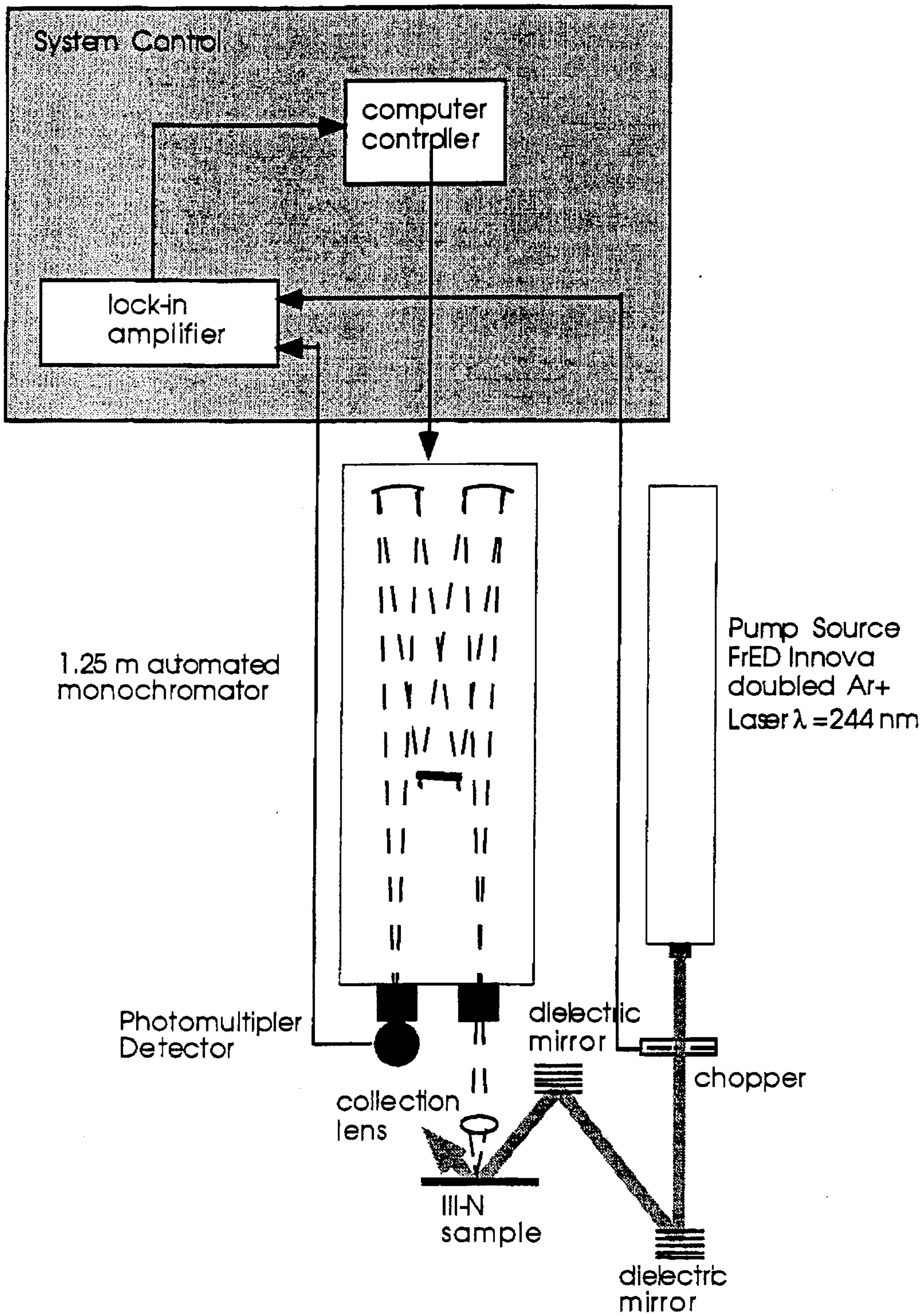

Figure 4. The III-N Photoluminescence System built around the FrED Innova double Argon 244 nm laser.

The Inova FrED 244 nm Pump Laser (Coherent Inc.) has now been fully integrated into the photoluminescence (PL) set up (figure 4.) This system allows rapid measurement of room temperature PL spectra as required for identification of alloy composition (figure 5) and III-N material quality. The PL measurement of bandgap and alloy composition is particularly useful for AlGaN alloys containing small mole fractions of AlN, which can not be determined by XRD measurements. (AlN and GaN are closely lattice matched so the X-ray peak separation is small. Mosaicity broadening of the XRD peaks makes XRD determination of AlGaN compositions in the <10% AlN mole fraction range very difficult.)

The absence of surface states in GaN and its related alloys allows useful PL measurements to be made on thin III-N layers. Furthermore, by using different pump wavelengths (which have different absorption lengths) we can obtain PL spectra from different depths within the sample and measure vertical composition uniformity.

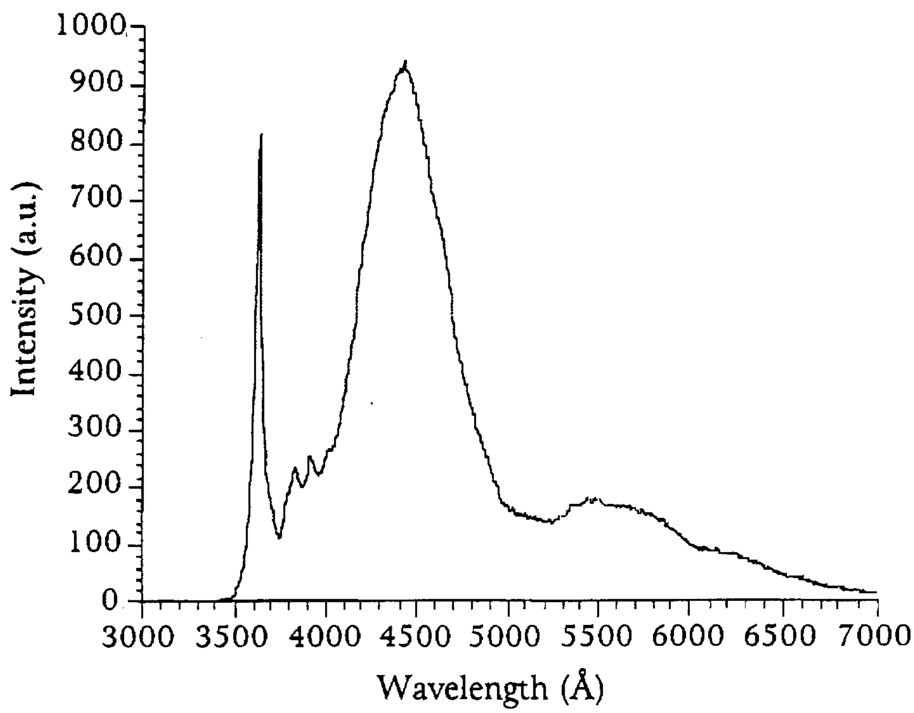

Fig. 5. A typical PL spectrum for an $In_{0.22}Ga_{0.78}N$/GaN heterostructure showing the sharp band edge peak for GaN at 365 nm and InGaN luminescence at 440 nm.

4. Associated References

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S.D.Hersee, J.Ramer*, K. Zheng, C. Kranenberg, K. Malloy, M. Banas and M. Goorsky, "The Role of the Low Temperature Buffer Layer and Layer Thickness in the Optimization of OMVPE Growth of GaN on Sapphire", J. *Electronic Matls.* 24 (1995) 1519-1523.

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